LOW COST AC POWER MONITOR FOR RESIDENTIAL PV SUPPORT

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ABSTRACT

The rate at which new, residential on-grid PV systems are being installed increases every year. Yet, most include virtually no metering, customer education or other support for the system owners. The California Energy Commission's *Renewable Energy Program Evaluation,* October 2000 [1], stated that consumers need a basic level of system performance measurement in order to verify whether their system is operating properly. This echoes a recurring observation that has been made by researchers, at least, since 1990 [2].

Consumers can turn to after-market meters which exist, but these are often inaccurate and none supports remote display. Of equal concern is that manufacturers of most meters assume a basic knowledge of electrical power that homeowners do not possess. To help meet this long-standing need, an inexpensive, accurate, ac power monitor has been developed for installation by an untrained homeowner. This monitor incorporates a power line carrier remote display that can be located anywhere in the home. The monitor and associated training materials have been designed to teach consumers to accurately assess PV system performance and recognize system failures. It is hoped that the unit's low cost and potential consumer value will demonstrate commercial viability.

INTRODUCTION

Background

Residential, rooftop, grid-interactive PV is not new. As early as 1985, utility and developer sponsored demonstration projects installed PV arrays on 30 homes in Gardner, MA, and 36 townhomes in Laguna Del Mar, CA. One of the authors had occasion to test the 30 PV systems in Gardner, MA in 1989. At that time, the enthusiasm of these pioneer, PV-advocating homeowners was impressive. But, all found it necessary to ask the same question: is it working? Starting with these early systems, researchers were advocating that homeowners be provided with monitoring instruments to assist them with the use of their PV systems [2].

The costs of today's PV systems are a fraction of what they were in the 1980's, but PV energy cost is still a premium, averaging $0.43/kWh by one estimate [1]. Basic consumerism and the obvious need to make the best use of an expensive investment, lead today's customers to want the same assurances their predecessors wanted: that a purchased system is working and performing according to specifications.

Present situation

Most residential PV systems are installed without any instrumentation, but several after-market ac power and energy meters are available. Generally, costs for these devices range from approximately $190 (U.S.) to over $600. In the authors' experience, none has provided the complete support needed by most residential PV customers. From experience, some devices have been found to be inaccurate. Some measure power flow in only one direction (disregarding inverter standby losses at night). Some units have had unreliable service histories. None includes a remote display, thus requiring the homeowner to go to the meter to take readings. Finally, in no cases have the authors found any after-market instruments which include tutorial information sufficient to adequately help an untrained homeowner identify or troubleshoot difficult PV system problems.

THE LCAP PROGRAM

To support the growing number of PV customers and promote the successful growth of the PV industry, the Low Cost AC Power Monitor (*LCAP*) development program was begun. The *LCAP* program was started in December 2001 with the following goals: 1) to design an accurate, real-time ac power meter which meets IEC1036 Class 1 specification for accuracy; 2) to include microprocessor control for signal processing, energy logging and communications; 3) to configure an instrument that can be safely installed by an untrained homeowner; 4) to support a remote display that can be placed anywhere in the home for ease of observation; 5) to include training materials that will inform the PV user of PV fundamentals and the effective use of the metering hardware for system diagnostics; and 6) to cost less than $100 to manufacture.

Class 1 metering circuitry

The heart of *LCAP* is a metering circuit based on a dedicated IC from Analog Devices, the AD7750. This IC is designed for use in power metering applications, accepts two differential analog input channels (voltage and current), produces a product of these two channels, and has been designed to meet the IEC1036 Class 1 meter specifications. Among its advanced features are integrated high-pass and low-pass filters, an internal differential gain amplifier, and complete four-quadrant operation (accurate when the inverter is either producing power during the day or dissipating power at night). The chip's error as a percent of reading is less than 0.3% over a dynamic range of 1000:1.

Microprocessor control

The *LCAP* is a microprocessor based instrument and incorporates an off-the-shelf, low-cost, single board computer. The use of a microprocessor enables regular self-calibration, software-based signal processing, and supports data logging and communications.

Like all instruments, *LCAP* is subject to calibration and zero drift over time. The instrument's software automatically provides a self-calibration function and determines and nulls zero drift on a regular basis. These functions ensure accuracy and are transparent to the user.

The *LCAP* unit is capable of recording time-stamped hourly average, maximum, and minimum power values for up to 5 months without overwriting old data. Stored data can be collected by a PC or telephone modem, if supplied. Real-time readings are available on a local 2 line by 24 character display, via serial cable to a PC, or on the remote display (see below).

User-installable sensors

All power meters must sense both voltage and current in order to calculate power. The LCAP uses sensors which do not require rewiring of the inverter for installation. Where system installation will allow access, all sensors can safely be installed by an untrained homeowner.

Current is sensed using a split-core, current transformer with an internal burden resistor across its secondary winding. This resistor converts transformer output from a current to a voltage but, more importantly, prevents arcing if the transformer is removed from the circuit under load. The split core transformer clamps onto the inverter's ac current carrying wire. Voltage sense is achieved using a conventional ac outlet plug. Inserting the plug into the outlet provides the connection. Alternatively, the voltage sense wires can be connected to terminal screws such as in an ac distribution panel. Voltage sense wires are protected by series fuses.

Remote display capability

Sensor requirements dictate that the metering hardware be located either near the inverter or the home distribution panel. These are often located outside or in a garage or basement and not someplace where they can be easily observed. The metering information is most useful if it can be observed where the homeowner regularly goes – perhaps in the kitchen or by the front door.

A unique feature of *LCAP* is its support for a remote, real-time display. To achieve this, the metering circuit and remote display communicate via powerline carrier. With powerline carrier communications, an encoded signal is modulated onto the household power wiring with a special transceiver plugged into a conventional outlet. Other transceivers located throughout the house can receive this signal if they are also plugged into power outlets. At present, transceivers based on the X10 protocol have been used.

User training materials

A key component of the *LCAP* program is an integrated set of training materials designed especially for a homeowner. The training materials are designed to teach the homeowner simple PV fundamentals. They also explain how a grid-connected, rooftop PV system works in general, how to install *LCAP* hardware, how to take and use real-time readings with *LCAP*, symptoms to look for if system output is low and simple troubleshooting methods. Finally, they explain how to collect and use the logged data.

EXPERIENCE TO DATE

Work completed

The metering circuit was initially designed and built on a breadboard. Early designs were tested, revised, and optimized. Test results for the present, optimized design are excellent. The basic circuit and sensors meet the design specifications for accuracy when reading ac power levels from 10 W to 5 kW. In addition, test results show that accuracy is maintained over a range of power factors from 0.5 leading to 0.5 lagging. A printed circuit board has been designed (see Fig. 1) and six *LCAP* units have been built using these boards.

The software for the single board computer is 90% completed. The software functions that read hardware inputs and calculate ac power are completed. Similarly, all software required to support real-time communications and hardware self-calibration have been finished and tested. The final routines for data logging are all that remain and these will be finished within the next few weeks.

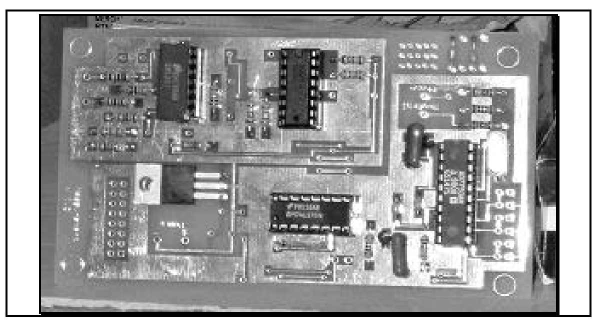

Fig. 1. Completed *LCAP* printed circuit board.

The training materials are being developed and are approximately half completed. The final text will be developed with feedback from *LCAP* actual users during the field demonstration phase which will is scheduled to be conducted this summer (see below).

Work remaining

One feature of *LCAP* which has not yet been successfully implemented is the remote communication and display. Attempts to use X10 transceivers have not yielded a reliable communication link. X10 is a simple standard and protocol designed for household functions such as dimming lights and switching on and off appliances. It was chosen because of its low cost and with the understanding that *LCAP's* use of the protocol would push its boundaries into a data communication function for which it was not originally designed.

With the unsatisfactory results of X10, other protocols and hardware are presently being evaluated. Promising results are beginning to be obtained using hardware and software compliant with the CEBus (Consumer Electronics Bus) standard. CEBus is an open standard which is rapidly spreading for home automation and networks. Its major drawback is cost – costing three to four times what the equivalent X10 transceivers cost.

The cost to build the basic LCAP unit did not come in under $100 as desired. The unit cost for the current configuration is approximately 30% higher than this for the initial quantities built (six units). It is to be expected that the addition of CEBus compliant hardware necessary to implement a reliable remote display will add to the cost of the final design.

FIELD DEMONSTRATION PROGRAM

Six *LCAP* units are now built. Beginning this summer, these six will be installed in homes with on-grid PV systems in California. Each of the six homes already has a dedicated DAS. The demonstration program will evaluate the use of *LCAP*. The value it provides for real-time assessment of system performance, system diagnostics and PV user satisfaction will all be assessed. The users will be instrumental in providing feedback on the level, quantity and quality of the training materials.

FUTURE DEVELOPMENT

Once the field demonstration program is concluded, the hardware design and training materials will be reviewed for completeness. At that time, *LCAP* development will be complete.

Southwest Technology Development Institute is a research department at New Mexico State University and does not manufacture products for sale to the public. SWTDI will make the LCAP hardware, software, and documentation available to private companies expressing an interest in producing and marketing them. The mechanism for this will likely be a licensing arrangement between each company and New Mexico State University– for $1 per year. The hope is that the PV-purchasing public will gain a valuable tool that will help them to better operate their systems, increase their satisfaction with PV, and , in this way, promote the PV industry.

REFERENCES

[1] Regional Economic Research, “California Renewable Energy Program Preliminary Evaluation”, *Published by the State of California Legislature*, October 2000.

[2] M. Russel and E Kern, “Lessons Learned with Residential Photovoltaic Systems”, *Proceedings of 21st PVSC*, 1990, pp. 898-902.